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File system on CRDT*

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Abstract: In this report we show how to manage a distributed hierarchical structure representing a file system. This structure is optimistically replicated, each user work on his local replica, and updates are sent to other replica. The different replicas eventually observe same view of file systems. At this stage, conflicts between updates are very common. We claim that conflict resolution should rely as little as possible on users. In this report we propose a simple and modular solution to resolve these problems and maintain data consistency.

Key-words: Distributed System, CRDT, Optimistic Replication, Data Consistency, File system

* This work is a deliverable of french national research programs ConcRDanT (ANR-10-BLAN-0208).

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Les système de fichier comme graphe en CRDT²

Résumé : Dans ce rapport nous allons montrer comment gérer une structure hiérarchique structuré représentant un système de fichier. Cette structure est basé sur la réplication optimiste, chaque utilisateur travaille sur une copie local et les mises à jour sont envoyées aux autres réplica. Les différentes répliques observent éventuellement la même vu du système de fichier. Á ce stade, des conflits entre les mises à jour peuvent avoir lieu. Nous demandons l'intervention des utilisateurs pour résoudre les conflits aussi peu que possible. Dans ce rapport, nous proposons une solution simple et modulaire pour résoudre ces problèmes en maintenant la cohérence des données.

Mots-clés : Système distribué, Système de fichier, CRDT, Réplication optimiste

²Ce travail est aussi un livrable de l'ANR ConcrDanT (ANR-10-BLAN-0208).

1 Introduction

Distributed file systems allows different users to work collaboratively on large-size projects, such as the collaborative development on the Linux kernel. When a file system is distributed, many technical and usage issues should be considered and addressed. As such issues, we can cite all the issues relative to local file system plus other due to distribution: network communication, privacy insurance, distributed access control, fault tolerance, replica distribution, user coordination, etc. In this report, we only consider the problem managing concurrent updates on the file system.

Indeed, when multiple people share and modify the same file system concurrently, the updates can interfere with each other in such a way that the file becomes useless and contains conflicts. Some traditional distributed file systems recommend file locks to ensure that the file is protected. Unfortunately, this method cannot ensure high responsiveness for real-time collaboration or disconnected work, because the initiator of an update should acquire an exclusive access. On the other hand, optimistic replication [11] allows availability, performance and supports work in disconnected mode. In an optimistically replicated file system, data is replicated on each replica, and any replica can independently modify its own state. However, optimistic mechanisms gain this availability by trading off linear consistency.

Anyway, all modifications are sent to other replicas and some consistency must be ensured. Strong eventual consistency (SEC) ensures that as soon as replicas have received the same updates, the replicas host the same data value [13]. Depending of approach used, these modifications can be sent as a set of update operations (aka *operation-based*), or sent as a whole new state (aka *state-based*). Most of version control systems (VCS) such as Subversion [1] or Git [15] adopt state-based approaches, while distributed file systems described in the literature [5, 4] are mostly operation-based.

In eventual consistency, since any replica can be updated, two modifications applied independently may lead to conflicts. For instance, the addition of a file in a directory conflicts with the removing of this directory. To maintain a correct hierarchical data type, a system with optimistic replication must either avoid such conflicts or recover automatically from them. Conflict-free Replicated Data Types (CRDT) [13] can be a solution.

This report is structured as fellows. Firstly, we give a state of art to talk about an existing file systems. The next section presents an overview of the Conflict-free Replicated Data Types (CRDT). After that, we begin a definition of CRDTs generally and describe more precisely the different solutions to build CRDT based on set structure. The next section 4 shows a new data structure based on layers that ensure consistency. Section 2 discusses about file system and a conflicts that can arise in an optimistic replication system, we describe briefly how conflicts are detected and cover. The next section 4.2 describes the solution using CRDTs to manage conflicts. Finally, we close with a conclusion.

2 File System

In this section we present the data type corresponding to a hierarchical file system. We define the structure of this data type and the update operations

that can be applied on it. Finally we describe the possible conflicts that can arise in with such a replicated data structure.

We consider the data structure of file system as a tree containing elements with a typed content. A content type can be a directory – that contains other element elements – or file types. We consider that file types are automatically detected by the replicated system. For instance, version control systems consider text and binary file types. For shake of simplicity, and as many of heavily used replicated file systems [3, 5], an element is only present once in the tree. I.e., we do not manage soft or hard links.

Definition 1. A file system element is couple (n, c) where n is the name of the element and c is its content. There exists a function $\text{type}(c)$ that returns the type of the element according to its content. The content of a directory is a collection of elements where each name is unique. A file system is a root directory with an empty name.

We consider the basic operations *add*, *remove* of files and directories, and *update* of files. Operations are defined according absolute paths.

Definition 2. A path is a list of element names $n.n'.n''.\dots$. The predicate $\text{exists}(p, S)$ for a path p and a file system S is defined recursively as follow:

$$\begin{aligned} \text{exists}(\emptyset, c) &= \text{true} \\ \text{type}(c) = \text{directory} \wedge \exists(n', c') \in c &\implies \text{exists}(n'.p, (n, c)) = \text{exists}(p, c') \\ \text{else} &\implies \text{exists}(n'.p, (n, c)) = \text{false} \end{aligned}$$

The function $\text{content}(p, S)$ returns the content of the element at path p in S . The predicate $\text{prefix}(p', p)$ is true if and only if the list p' is a non-strict prefix of the list p .

The operation $\text{add}(p, n, t)$ adds an element with name n and an empty content of type t under the path p . The operation $\text{remove}(p)$ (or $\text{rmv}(p)$) deletes the last object (file or directory) of path p .² Whereas $\text{update}(p, u)$ apply modification u on the file located at path p .³ We consider that each file content is managed by a conflict-free replicated data type (CRDT) [13] corresponding to the type of file. For instance text files can be managed using sequence CRDT algorithms such as WOOT [8], Treedoc [9], Logoot [16], or RGA [10]. Binary files can be managed using a Thomas-write-rule [14]. Moreover, any kind of file type can be managed such as sets, graphs [12] – or more usefully – XML files [7].

The usage of all the above operations must follow some pre and post conditions. The pre and post conditions are local, i.e. they must be ensured when a local modification is done atomically on a replica. When applied remotely, if the precondition is not respected, a conflict occurs. The respect of the post condition depends on how the conflict is resolved.

- $\text{pre}(\text{add}(p, n, t), S) \equiv \text{exists}(p, S)$ and $\text{type}(\text{content}(p, S)) = \text{directory}$ and $\neg \text{exists}(p.n, S)$

²We consider the more general case where any path, including non-empty directory can be removed.

³As some existing distributed file systems or VCS, we may restrict the set of operation to only *remove* and *update*. However, for shake of clarity in conflict presentation, we kept the *add* operation.

- $post(add(p, n, t), S) \equiv exists(p.n, S)$ and $type(content(p.n, S)) = t$ and $isEmpty(content(p.n, S))$
- $pre(remove(p), S) \equiv exists(p, S)$
- $post(remove(p), S) \equiv \neg exists(p, S)$
- $pre(update(p, u), S) \equiv exists(p, S)$ and u is applicable on type $content(p, S)$
- $post(update(p, u), S) \equiv exists(p, S)$ and $content(p, S)' = content(p, S) \circ u$

With such pre conditions, in case of a concurrent modifications, some conflicts occurs:

- $add(p, n, t) || remove(p.n)$: adding and removing the same element concurrently
- $add(p, n, t) || remove(p')$ with $prefix(p', p)$: adding an element while removing one of its ancestors
- $add(p, n, t) || add(p, n, t')$: adding two element with same name under same directory
- $update(p, u) || remove(p')$ with $prefix(p', p)$: updating an element while removing one of its ancestors

Contrary to existing distributed file systems we do not consider the $update(p, u) || update(p, u')$ conflict since file contents are CRDT. Thus, concurrent updates operation can be applied in any order while obtaining eventual consistency. The remainder of this section will discuss the conflicts occurrence in more detail. The next section describes how we manage these conflicts.

Even a simple collaboration of two replica can result in a conflict. Figure 3 illustrates this situation. Directory *Toto* appears on two replicas. Replica 1 creates a file *prog.c* under directory *Toto* when replica 2 removes *Toto*. Then, when the replicas merge, the pre-condition of $add(Toto, "prog.c", t)$ is no-longer true since the directory *Toto* is not present. This is an $add(a) || remove(b)$ conflict.

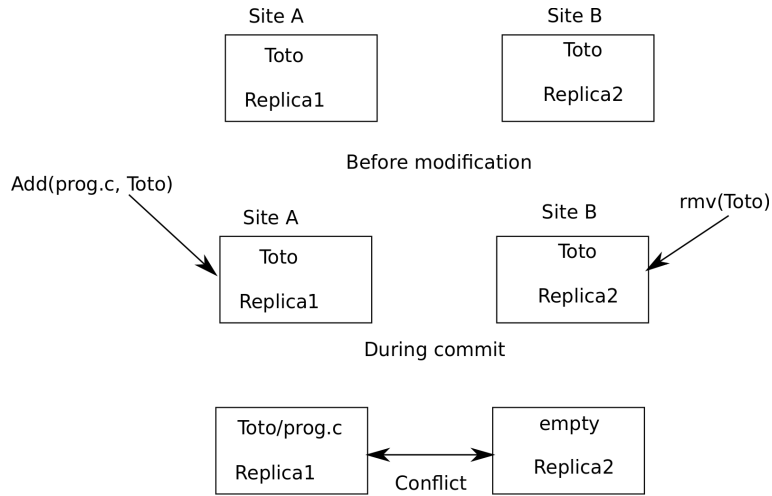


Figure 1: Conflict $add(a) || remove(b)$

Figure 2 illustrates a different kind of conflict where two users create a same document with same name. In figure 2 replica 1 creates a document *file* under directory *Toto*, with the same type. Replica 2 also creates *file* under directory *Toto*. During the integration of the remote update, the pre-condition of the second *add* operation (added path is not present in the file system) is violated. If the types of the concurrent *add* are the same, the system trivially ensures SEC. We term this $add(a)||add(a)$ conflict *name conflict*.

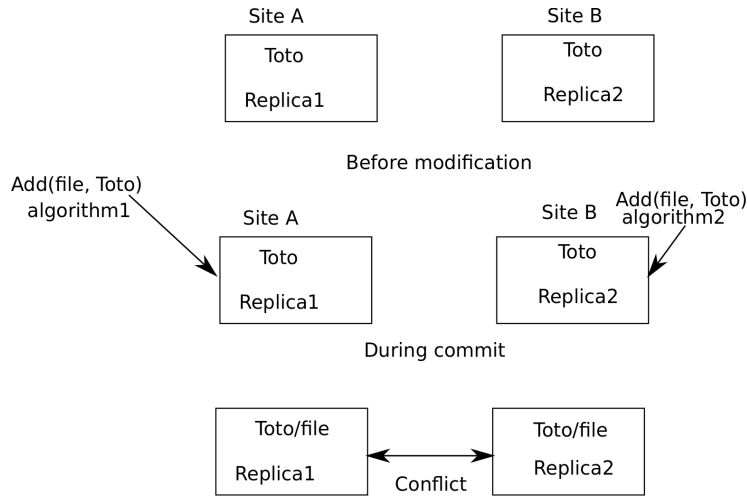


Figure 2: Conflict $add(a)||add(a)$

Another type of conflict is $add(a)||remove(a)$. Indeed, an element can be deleted and added at the same time. If replica 1 adds an element *a* when replica 2 removes it, divergence occurs.

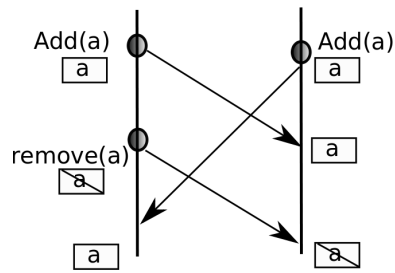
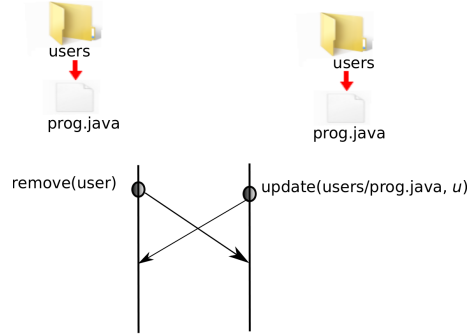


Figure 3: Conflict $add(a)||remove(a)$

The last type of conflict is $update(a)||remove(b)$. This conflict occurs when a replica updates a file content while another removes the file or a directory in the path to the file. In this case the precondition of the update operation (the path is present) is violated.

Figure 4: Conflict $update(a) || remove(b)$

Our goal is to design a conflict-free replicated data type (CRDT) for file system. So we need one or more replicated data structure where such conflicts either cannot occur or are resolved in an automated manner. Of course, the obtained data structure must ensure strong eventual consistency.

2.1 Ficus

Ficus file system[4] is developed for peer-to-peer optimistic file replication systems. The conflict possible in Ficus are :

- *Update/update conflicts* : It moves the file into a special directory called an *orphanage*. Each volume has its own orphanage directory located under its root directory
- *Name conflicts* : It occurs when user insert two file with same name under same directory. Ficus appends unique suffixes to each file name.
- *Remove/update conflicts* : Ficus allows users to resolve conflict.

Ficus propose also a mechanism to resolve a conflicts automatically except for name conflicts.

2.2 Version Control Systems

Version Control Systems manage files that can be accessed and updated by multiple user. Today, there are several types of these systems used such as CVS, SVN, GIT ... ect. These systems allows multiple users to work concurrently on a file while ensuring that their work is safe and not will be lost. Most of these systems are state-based and merge can be only done manually by a user. When a user wants to merge concurrent modification, he obtains a “best effort merge” where some of the conflict (depending on the system) are resolved automatically, while other have to be resolved by the user before it commits the merge. The committed merge is a new state in the graph history of the repository, so no conflict occurs on the repository.

Types of conflicts presented to the user depend on the structure and data management by the system. For instance, Git [15], does not take into account the directories, it considers the file system as a hierarchical set of files, while CVS and SVN consider the directories.

On the other hand, a case of divergence can occur depending of data management. In Git [15], the directories are considered only locally. When user create

locally an empty directory, git does not take it into account in the repository. When users make an update as in figure 5, two replica may observe a divergence while there are both up-to-date.

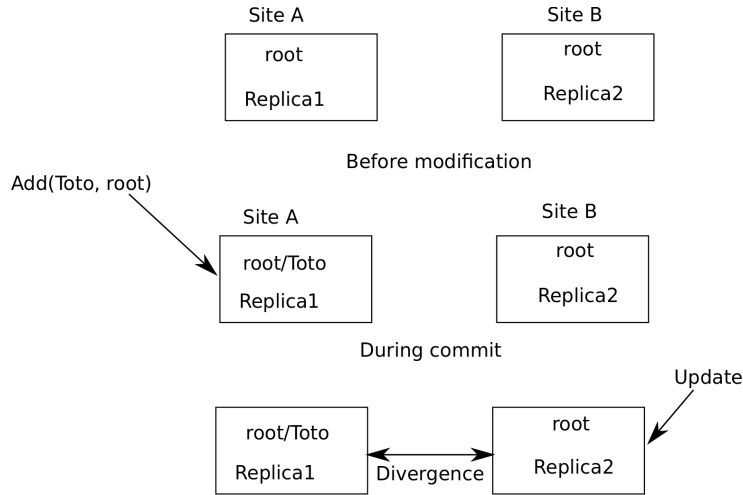


Figure 5: Divergence on git[15]

3 Conflict-free Replicated Data Types (CRDT)

To achieve high responsiveness, data replication is necessary. When the replicated data is mutable, the consistency between the replicas must be ensured. The CAP theorem [13] states that a replicated system cannot ensure strong Consistency together with Availability and Partition tolerance. In many applications, such as collaborative application, where availability is required by users and partitions are unavoidable, a solution is to allow replicas to diverge temporarily and when system is idle, all users observe the same data.

This kind of consistency model is called “eventual consistency” which guarantees that if no new update is made to the object, eventually all accesses will return the same value. The “strong eventual consistency” (SEC) model guarantees that all accesses return the same value as soon as all update are delivered. To ensure SEC, a particular merge procedure is required that handles possibly conflicting concurrent modifications.

In what follows you exemplify the CRDT principle by describing some replicated set designs.

3.1 Set

For a CRDT set, we consider two operations: a process can add an element with operation `add(a)` and can delete it with operation `remove(a)`. In a sequential execution, the “traditional” definition of the pre- and post-conditions are

- $pre(add(a), S) \equiv a \notin S$
- $post(add(a), S) \equiv a \in S$

- $pre(remove(a), S) \equiv a \in S$
- $post(remove(a), S) \equiv a \notin S$

In case of concurrent updates, the preconditions of $add(a) || remove(a)$ conflict.

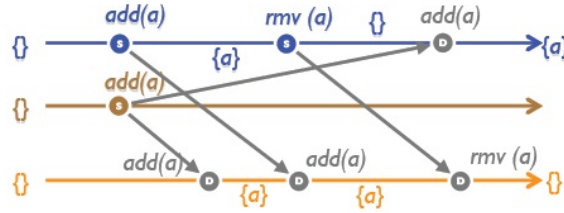


Figure 6: Set with concurrent addition and remove [12]

Thus, a set CRDT has different global post-conditions in order to take into account the concurrent updates while ensuring eventual consistency. Each CRDT has a *payload* which is an internal data structure not exposed to the client application, and *lookup*, a function on the payload that returns a set to the client application. For a set CRDT, the pre-conditions must be locally true on the *lookup* of the set.

In [12] different CRDT sets are described.

G-Set In a Grow Only Set (G-Set), elements can only be added and not removed.

2P-Set In a Two Phases Set (2P-Set), an element may be added and removed, but never added again thereafter.

LWW-Set In a Last Writer Wins Set (LWW-Set), each element is associated to a timestamp and a visibility flag. When two concurrent operations occur, an operation with a higher timestamp is executed.

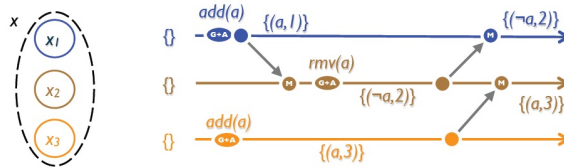


Figure 7: Last Writer Wins Set : LWW-Set [12]

C-Set In a Counter Set (C-Set), each element is associated to a counter. When user add element a counter is incremented, and when user remove an element is decremented. A local *add* can occurs only if $counter \leq 0$ and sets the counter to 1. A local *remove* can occurs only if $counter > 0$ and sets the counter to 0.

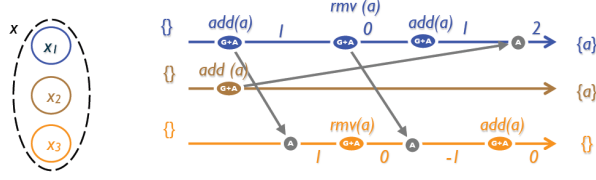


Figure 8: Counter Set : C-Set [12]

OR-Set In a Observed Remove Set (OR-Set) each element is represented by a unique tag on the set. A local *add* creates a tag for the element and a local *remove* removes all the tag of the element.

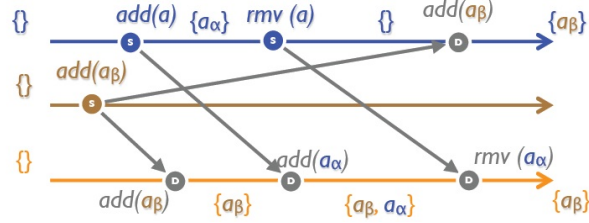


Figure 9: Observed-Remove Set : OR-Set [12]

4 Layer structure

To be able to control and manage conflicts simply, the structure of the system is managed by layers. Conflict resolving is invisible to the user application. A layer is represented by a component with the following interfaces:

lookup the method allows to see the data state; this method represents what users observe.

update the method allows to perform modifications on the data.

replication the lower layer (and only it) performs communication between replica.

Only the lower layer ensure replication and eventual consistency. The other layers computes a view from the lookup result of their above layer. Each layer is responsible for a particular constraint :

replication This first layer ensure communication between replica and eventual consistency. It ensure the constraint that a unique element identified by a path and a type is associated to a unique content. It encapsulates a set CRDT such as described previously, Section 3.1 and thus, resolves the conflict $add(a) || remove(a)$. The encapsulated managed set contains elements, i.e. couples $(path, type)$. Beside this set, the replication layer maps each file to its content, a CRDT, and resolves the $remove(a) || update(b)$ conflict. The lookup method of the layer returns a map $(path, type) \rightarrow content$. For directory, the content is empty, the children of a directory is determined

using paths of other elements. However, a set of path is not a file system data structure since other constraints must be ensured.

hierarchical The second layer is in charge to produce a connected tree view from the set of elements provided by the replication layer. To produce this tree view, the lookup method of this layer has to resolve the conflict $add(a) || remove(b)$ which creates orphan nodes. When the update is invoked, it transforms an element in the view into a path for updating the set. To obtain this path it must take into account how conflicts were resolved by the lookup method. To resolve the conflict several type of policies can be defined (see Section 4.2). In a tree view returned by this layer, a directory may contains several element with the same name (but different types and/or different original path).

naming The third layer ensure uniqueness of element names in directories. The lookup method of this layer return the file system data structure. In Section 4.2, we present two mechanisms to obtain unique names, either by avoiding conflict, either by returning a view where original names are changed in case of conflict.

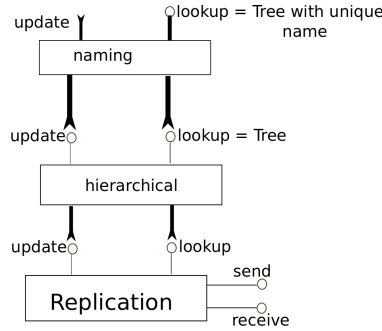


Figure 10: Layer structure

The advantage of this layered management is twofold. First, eventual consistency is ensured by well-known existing CRDTs. Since the other layers lookup methods only compute a view, without affecting the inner replicated state, SEC is ensured. Secondly, such a layered management allows to combine different solutions for conflict management in order to obtain a replicated file system. Since each conflict resolution has its own behavior, and its own computational cost, we give to the distributed application developer the entire control on the replicated data structure.

4.1 Replication Layer

As described above, the replication layer ensure strong eventual consistency. The update interface of the layer accept three operation $add(a)$, $remove(a)$ and $update(a, u)$ with a a couple $(path, type)$ and u and update compatible with the file type of a . The lookup interface return a map $(path, type) \rightarrow content$ with empty content for directories.

The layer encapsulates a set CRDT that contains couples $(path, type)$ to manage the $add(a)||remove(a)$ conflict. Beside this set, the replication layer maps each element to its content, a CRDT. The layer keeps content of deleted files. If the content is not kept, the data would diverge when the element is re-added, See Figure 11. Since the couple $(path, type)$ is invariant during time, every update is applied on the content of the element, and eventual consistency of the file content is ensured. This strategy also resolves the $remove(a)||update(b)$ conflict since both the file is removed and the content is updated.

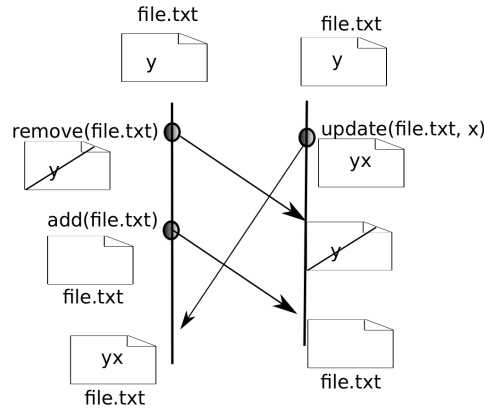


Figure 11: Layer structure

However, such tombstone contents should be garbageed somehow. Also, to ensure the local $add(a)$ post-condition – the content is empty –, the local “add file” update must create a couple of operations: $add(a)$ that makes the file visible and $update(a, u)$ such that $isEmpty(content(a, S) \circ u)$, i.e. an operation that clears the file content.

4.2 Hierarchical Layer

This layer is in charge to produce a tree from the set of paths obtained with the replication layer. It is in charge to manage the $add(a)||remove(b)$ conflict where b is an ancestor of a . To manage this conflicts we propose two kind of solution. The first kind ignores directory and consider only files, and thus avoid such a conflict. The second kind resolve the conflict by treating with different possible policies the orphan elements that result from such a conflict.

In both kind of solutions the lookup interface of the layer returns a tree which labels are tuple $(name, type, path, content)$: the name of the element with its type and its original path (the path appearing in the set). The update interface allows to apply the following operations: $add(p, n, t)$, $remove(p, t)$ and $update(p, t, p', u)$ with p a path in the lookup tree, n a name, t a type, p' the original path and u a content update.

4.2.1 Consider only leaf

The first kind of hierarchical layer, consider only the leaf of the file system. The type “directory” no longer appears in the inner replication layer. To avoid

the conflict $add(a)||remove(b)$ we change a pre and post condition described previously (Section 2).

- $pre(add(p, n, t), S) \equiv exists(p, S)$ and $type(content(p, S)) \neq directory$ and $\neg exists(p.n, S)$
- $post(add(p, n, t), S) \equiv exists(p.n, S)$ and $type(content(p.n, S)) = t$ and $isEmpty(content(p.n, S))$
- $pre(remove(p, t), S) \equiv exists(p, S)$.
- $post(remove(p, t), S) \equiv \neg exists(p, S)$.
- $pre(update(p, t, p', u), S) \equiv exists(p, S)$ and u is applicable on type $content(p, S)$
- $post(update(p, t, p', u), S) \equiv exists(p, S)$ and $content(p, S)' = content(p, S) \circ u$

This solution has an impact on the inner layer. Indeed, the inner layer “replication” contains a set of couple (p, t) with p is a path directed to files and t is a type such that $type(content(p, S)) \neq directory$. Also, the lookup method of the layer returns a map $(path, type) \rightarrow content \neq \emptyset$.

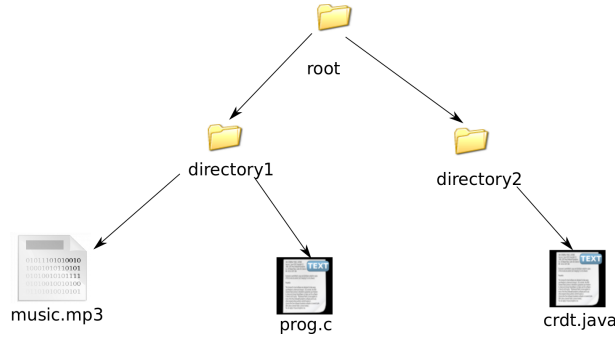


Figure 12: file system with binary file, text files and directories

Example : In the file system respresented in figure 12 the replication layer contains:

$$\{(root/directory1/music.mp3, type(music.mp3) = binary), \\ (root/directory1/prog.c, type(prog.c) = text), \\ (root/directory2/crdt.java, type(crdt.java) = text)\}$$

The “hierarchical” layer can computes a result tree by using two methods. First, is an incremental method. In this method, a layer stores the state of the data type that will be returned to the upper layer and it modifies this data type each time its inner layer state is modified. The case of non-incremental method, the lookup recomputes the tree each time its inner layer state is modified. In both methods, the tree view returned by this layer is not ready to represente a right file system since a directory may contains several element with the same name.

The update interface transforms the elements in the view into a path to invoke an update of the inner layer.

GIT[15] is based on tree where each file is defined by unique path started by root. The directories are created on the fly and they represent just a logical representation to the users. Unlike in our method proposed, in git we can observe a small divergence. Indeed, if user located in replica 1 creates an empty directory and commit, a file system as git does not take into account this empty directory, then, when user 2 makes an update, the two replica does not observe the same content.

4.2.2 Treat orphan nodes

Another kind of solution to manage the $add(a)||remove(b)$ conflict is to treat the orphan elements produced by the conflict. An orphan element is a path in the replication set which its father (its longest strict prefix) is not in the set. To treat orphans, several policies are described in [6].

The lookup interface obtained by these policies are the following.

skip This behaviour does not return orphan element; it gives priority to *remove*.

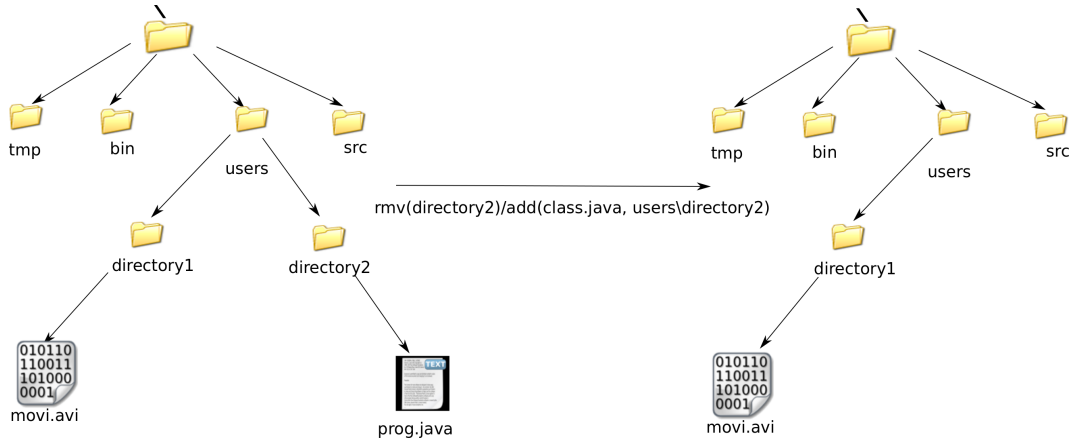
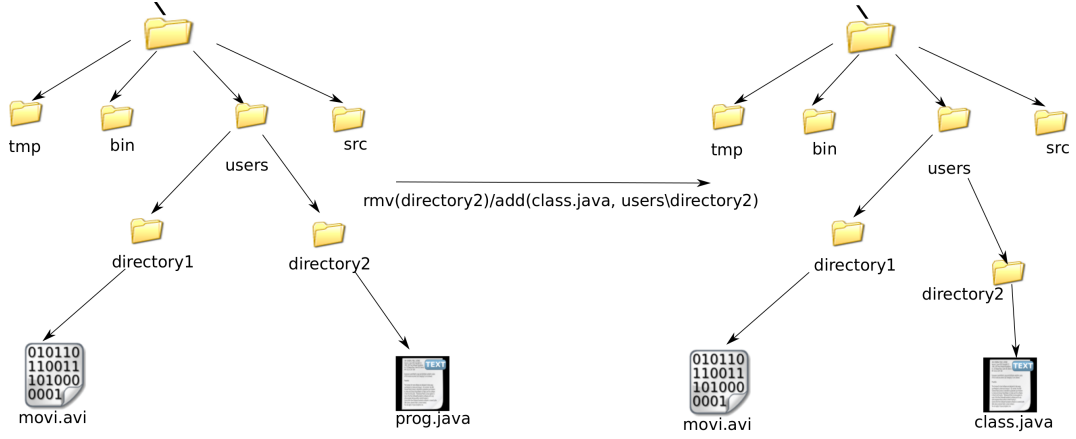
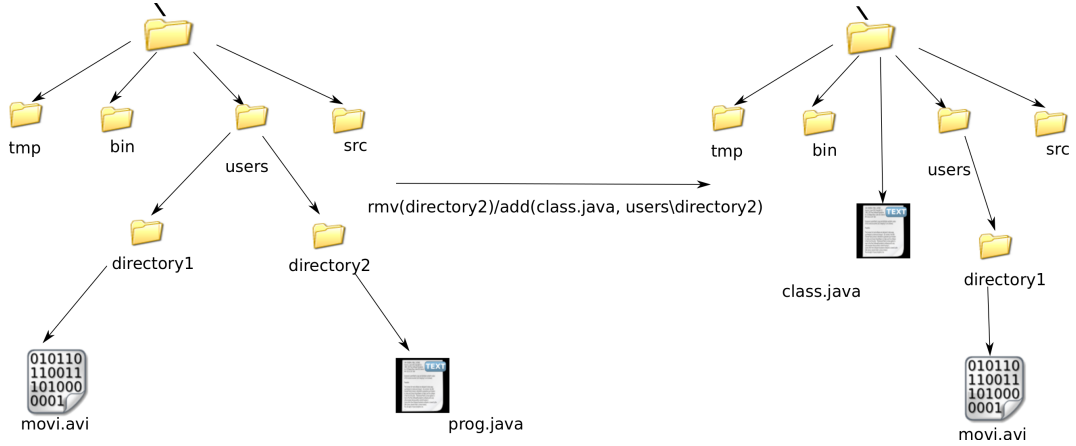


Figure 13: *skip* policy.

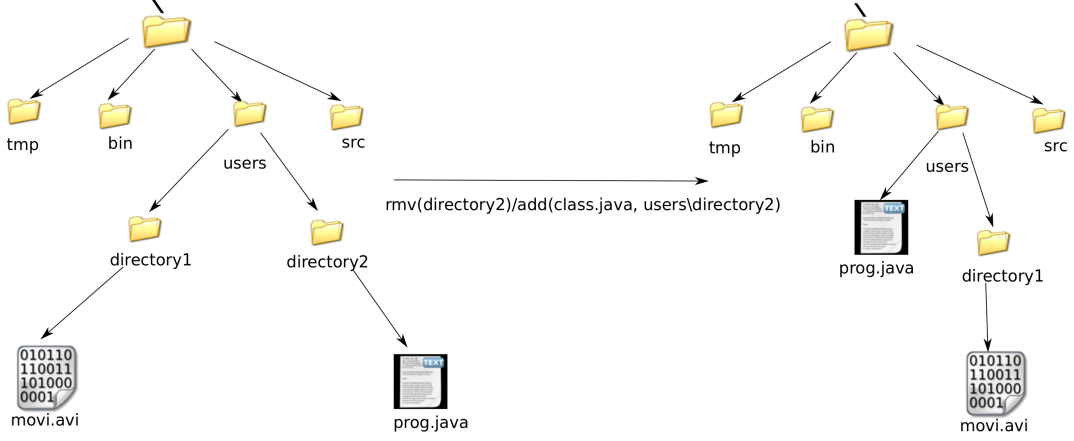
reappear This behaviour returns an orphan element at its original path; it give priority to *add*. All required ancestors are recreated in the view. However, when recreated directories are empty they are removed. This solution has a behavior similar than “*Consider only leaf*” solution, except than it allows the tree to contains empty directories.

Figure 14: *reappear* policy.

root This behaviour places orphan elements under the root. This behavior can also be used to place the orphan elements under some special “lost-and-found” directory as in Ficus replicated file system (see Section 2.1).

Figure 15: *root* policy.

compact This behaviour places an orphan element under the longest connected prefix path. In figure 16 when the file system receives a remove *directory2* and, concurrently, the addition of a file *prog.class* under *directory2*, this file is placed under the father of the deleted directory, i.e. *user*.

Figure 16: *compact* policy.

Each of these policies has a non-incremental version, where the view is entirely re-computed from the set and an incremental version, where the view is only updated when a change is made on the inner set. The update interface adapt path in the tree into path for the set. Due to choices made by the policies, these paths can be different. For instance, in Figure 16, *remove(/user/prog.class, binary)* will be adapted into *remove(/user/directory2/pog.class, binary)*. For details, see [6].

Until now, this mechanism returns a hierarchical structure, but it does not represent yet the file system. If two replicas add the same name under the same directory, this structure may confuse. To avoid this problem and construct a valid file system, we add a layer called *resolve name* that treats this type of conflict *add(a)||add(a)*. In what follows we present this layer and how it treats the conflicts. This layer also treat the case where several elements with same name and type (but different original paths) where placed in a directory by the “root” or “compact” policy.

4.3 Naming layer

The naming layer ensures that each directory contains only one instance one file with a given name. We consider that two files with the same type created twice concurrently at the same place is only one file and the content is merged. For elements with different types or origin, we propose two kind of solutions.

The first method avoid the conflict by altering preconditions of operation, i.e. it enforces some properties on elements names. The second method renames on-the-fly conflicting files, so it let users to resolve the conflict.

First method : We associate to each file type a specially algorithm. When a conflict occur, a file system merge two files since they implements the same algorithm.

- $pre(add(p, n, t), S) \equiv exists(p, S) \text{ and } \neg exists(p.n, S)$

- $pre(remove(p, t), S) \equiv exists(p, S)$.
- $pre(update(p, t, p', u), S) \equiv exists(p, S)$

In addition, the directories must not have an extension and text type are not permitted as an extension for binary files.

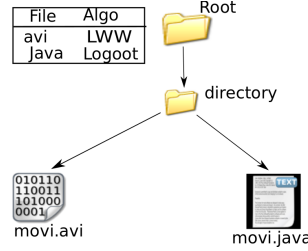


Figure 17: Different algorithm to each extension

In figure17 a tree observed by user is : $root/directory/movie.java$ and $root/directory/movie.avi$. When user makes modification in the file *movie.java*, an algorithm used is automatically *Logoot*. This method is not permitted for root and compact policies. Indeed, when a root or compact policies are applied, a file may located with another under same directory that was not in the same directory before. In this case, a merge is not permitted since we cannot merge two file with different origins.

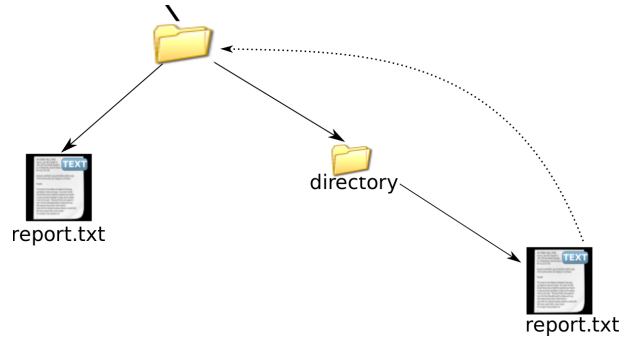


Figure 18: Two files conflict after root/compact

Second method : This solution is applied only when conflict occur. To distinguish between files, we add at the last of file name the name of the algorithm used or the origin path as an extensions. Finally we propose to users to choose one of the two files or merge them. In both case we keep only one file and we remove the extension added from the file name. So, users can observe a strange behavior of files since it changes name when conflict disappear (small glitch).

In both methods, a lookup interface returns a tree to user application without conflicts and with unique name. This tree is computed with incremental or non-incremental versions. In case of incremental version, the layer keep a state of the data structure and the conflict is detected directly when a method update is invoked. While, in case of non-incremental version, the layer recomputes all tree

each time the users make modifications. The update interface adapt operations in the tree to detecte and resolve conflicts names.

5 Conclusion

In this report, we have proposed a solution to represent optimistically replicated file systems. Our solution ensure strong eventual consistency. We use a CRDT tree to bypass the different conflicts using a layer structure. Using a layered approach, each conflict is managed separately. Thus, we give the choice to the developer to choose a specific policy to resolve a specific conflict automatically. Nonetheless, the final solution concerning unique names have some drawbacks, first, it changes a name of files in case of conflict which is not desirable to users, and second the conflict in some cases is resolved manually by users. However, this method gives more alternatives to developers compared to other methods.

Finally, our approach produce a best effort merge that may satisfy the application developer but not all the final user of the application. So such solution have to be coupled to an awareness mechanism [2] that allows the user to be conscious of the choice made automatically by the system and to produce updates that correspond to another choice.

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